MARDI Res. Bull., (1985) 13, 3: (249–269)

SHADE TOLERANCE POTENTIAL OF SOME TROPICAL FORAGES FOR INTEGRATION WITH PLANTATIONS 2. LEGUMES

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Keywords: Shade tolerance, Defoliation, Tropical legumes, Dry matter productivity, Light, Nitrogen.

RINGKASAN

Dalam penilaian perbandingan terhadap 14 jenis kekacang tropika yang ditanam dalam pasu di rumahkaca, *Calopogonium caeruleum* merupakan jenis yang lebih tahan terhadap naungan diikuti oleh *Pueraria phaseoloides, Alysicarpus vaginalis* dan *Desmodium ovalifolium*. Spesies-spesies *Stylosanthes, D. triflorum* dan *D. heterophyllum* adalah yang paling kurang baik terhadap naungan. Jenis-jenis yang mengeluarkan hasil bahan kering yang terbaik pada keseluruhan paras naungan terdiri daripada *P. phaseoloides, C. mucunoides* dan *C. caeruleum*. Pengurangan cahaya yang sesuai untuk fotosintesis (photosynthetic quantum flux – PHAR) sebanyak 44%, 66% dan 82%, memberikan hasil purata bahan kering yang berkurangan sebanyak 30%, 55% dan 71% berbanding dengan kawalan yang tidak mempunyai naungan di dalam rumahkaca tersebut. *Calopogonium mucunoides, C. caeruleum* dan *D. ovalifolium* memberikan tindakbalas kuadratik (quadratic response) dalam hasil berat kering terhadap paras-paras cahaya dengan paras optimumnya pada 57% cahaya yang digunakan untuk fotosintesis (PHAR) daripada cahaya yang sepenuhnya.

Dalam percubaan di ladang, *Stylosanthes guianensis* cv. Endeavour memberikan hasil bahan kering tahunan yang tertinggi pada semua paras naungan. Ini diikuti oleh *D. ovalifolium, C. caeruleum* dan *P. phaseoloides. Centrosema pubescens* menghasilkan bahan kering yang terendah. Pengurangan terhadap PHAR sebanyak 40%, 66% dan 82% daripada cahaya matahari sepenuhnya menghasilkan kekurangan purata keseluruhan hasil bahan kering sebanyak 36%, 43% dan 60% jika dibandingkan dengan kawalan (tanpa naungan).

Pada amnya, kelima-lima kekacang forej tersebut tidak dapat mengekalkan penghasilan bahan kering yang tinggi pada setiap kali potongan. Peratus bahan kering, keluasan permukaan daun dan nisbah pucuk/akar bertambah dengan peningkatan kadar naungan, tetapi berkurangan dalam peratus akar dan bilangan bintil-bintil akar. Peratus daun dan batang bertambah sedikit sahaja dengan peningkatan naungan. Keluasan permukaan daun bertambah dengan pertambahan yang tidak bererti pada paras naungan yang rendah, tetapi keluasannya berkurangan pada paras naungan yang tinggi.

Kandungan nitrogen berbeza di antara spesies-spesies, dan pada amnya bertambah di antara paras-paras naungan kecuali pada paras peningkatan naungan yang tertinggi di mana kandungannya berkurangan.

INTRODUCTION

In Peninsular Malaysia, there are over 2.1 million hectares of rubber, more than 1.1 million hectares of oil palm and 400 000 hectares of coconut, comprising over 80% of the total agricultural land used (MOK and THANG, 1983). These monospecific plantations are usually planted at wide spacings and during the establishment period, the wide interrows are often left unused or oversown with leguminous covers or interplanted with cash crops such as cassava, groundnuts, soybean and cocoa (WATSON, WONG and NARAYANAM, 1964; CHIN, 1977). Currently, many of the plantation legumes have been included in pasture mixtures for grazing in Africa (MOORE, 1962), Australia (HUMPHREYS, 1969) and Latin America (SANTHIRASEGARAM, 1976). They provide valuable improved tropical forages for ruminant production (WAN MOHAMED, 1977). However, the use of these plantation covers for livestock feed

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has not been fully exploited in the plantation sector in this country.

In a small country like Malaysia, with limited suitable and cheap agricultural land particularly for the ruminant industry, there is an urgent need to develop technologies to exploit the vast interrow areas in plantations for livestock integration, thereby assisting the country to intensify agricultural production per unit land (THOMAS, 1978; TAJUDDIN, CHIN and PUSPARAJAH, 1979).

Preliminary results on the utilization of improved tropical pastures in 5-year-old palms for livestock integration have been favourable (CHEN, CHANG, AJIT and HASSAN, 1978). Solar radiation decreases progressively under the plantation canopy as the crop matures, and thus light attenuation could become a major constraint in forage production.

As little is known of the effects of different light levels on the growth and regrowth of forages and plantation legumes and to what extent light limitation affects the nutritive quality and persistence of these legumes under the various stages of plantation growth, a pot trial complemented with a field trial was undertaken to assess the influence of different light levels on the overall growth performance and the chemical composition of some of the commonly used plantation covers and forage legumes in the country.

MATERIALS AND METHODS

Pot Trial

The experiment was initiated in May 1980 to assess the performance of 14 tropical legumes *(Table 1)* under four shade levels (inclusive of an unshaded control) in the greenhouse at MARDI Research Station, Serdang. The experimental design was a Randomized Complete Block in split-plot arrangement with three replications.

Lateritic clay loam of an Orthoxic Tropudult was mixed with 30% fine sand and 10% cattle manure. The soil mixture was then sieved through a 0.5 cm x 0.5 cm screen and air-dried.

Table 1. The 14 tropical legumes selected for study

Botanical name	Common name
Aeschynomene falcata (Poir.) DC.	Joint vetch
Alysicarpus vaginalis (L.) DC.	Alyce clover (US)
Calopogonium caeruleum	Caeruleum
Calopogonium mucunoides Desv.	Calopo
Centrosema pubescens Benth.	Centro
Desmodium heterophyllum (Willd.) DC.	Hetero
Desmodium ovalifolium (Prain) Wall. ex. Ridley	Ovalifolium desmodium
Desmodium triflorum (L.) DC.	Triflorum
Leucaena leucocephala (Lam.) De Wit	Peruvian leucaena
Pueraria phaseoloides Benth.	Puero
Stylosanthes guianensis (Aubl.) Sw. cv. Endeavour	Endeavour stylo
Stylosanthes guianensis (Aubl.) Sw. cv. Schofield	Schofield stylo
Stylosanthes hamata (Taub.) cv. Verano	Verano stylo
Zornia diphylla (L.) Pers.	Zornia

The plastic pots, 16.5 cm in diameter, were each filled with 2.5 kg of the air-dried soil. All pots received a surface application of basal nutrients equivalent to the following amounts:

Nutrient	**Amount (kg/ha)**
$NaH_2PO_4.4H_2O$	711
$KHCO_3$	750
$CaCO_3$	500
$MgCl_2.6H_2O$	50
$(NH_4)_6Mo_7O_{24}.4H_2O$	0.5
$ZnCl_2$	10
Na_2SO_4	100
$Na_2B_4O_7.10H_2O$	10
$MnCl_2.6H_2O$	10
$CoCl_2.6H_2O$	0.3

Seeds of the 14 legumes were initially scarified with sand paper, inoculated with the appropriate rhizobia and sown on 10

May 1980. Two weeks later, the seedlings were thinned down to 3 plants/plot and five weeks after sowing, the pots were transferred into their respective shade levels provided by varying the densities of screen cloth.

The screen cloth was stretched over the bench on a wooden frame, 1.5 m above the bench top and allowed to hang down on four sides of the benches to block off the morning and evening sun. The photosynthetic quantum flux (PHAR) of the transmitted light under the four shade levels was measured with a Lambda Li−185 light meter.

Since the greenhouse had reduced PHAR (64% of full sunlight), the light levels under the shade levels were expressed as percentages of the PHAR in full sunlight as shown in *Table 2.*

Table 2. Light levels under the various shade screens in the pot trial and in the field

Shade level	Photosynthetic quantum flux (%)	
Pot trial	In greenhouse	Outside greenhouse
SG 0	100 (control)	64
SG 1	56	30
SG 2	34	18
SG 3	18	9
Field trial	In full sunlight	
SF 0	100 (control)	
SF 1	60	
SF 2	34	
SF 3	18	

The pots were re-randomized once every week and watered twice daily to field capacity. Ten weeks after sowing, the plants were harvested to a 5-cm stubble height, and again after seven weeks. After the first harvest, phosphorus fertilizer in the form of triple superphosphate and potassium in the form of muriate of potash were applied at an equivalent of 30 kg P/ha and 50 kg K/ha respectively, to each pot.

All harvested materials were hand-sorted into leaf and stem fractions. The leaf fractions were sampled for leaf area determination using an electronic leaf area meter. All leaf and stem fractions were subsequently dried at 80°C in a forced-air oven for 48 hours to determine their dry weights. The root dry weight and nodule number were recorded at the end of the last harvest. The leaf and stem fractions were ground to pass through a 1-mm mesh steel screen. Kjeldahl analysis for nitrogen was done on the bulked plant tops of the two harvests. Other derived data taken included shoot/root dry weight ratio, leaf/stem dry weight ratio, specific leaf area, relative dry matter (DM) yields of tops, roots and leaves, nodule number, and regrowth vigour.

The overall comparison of the 14 legumes under shade was by rank comparison and the mean rank. All legumes were ranked, starting with 1 for the best and 14 for the worst with respect to all the ascribed characters. The most shade-tolerant legumes were those that had the lowest mean ranks.

Field Trial

A similar experiment was conducted in the field in June 1981 on an Orthoxic Tropudult soil at MARDI Research Station, Serdang to determine the influence of four artificial shade levels (100%, 60%, 34% and 18% PHAR of full sunlight) *(Table 2)* and two cutting frequencies on the performance of six tropical legumes. The legumes were caeruleum, puero, centro, hetero, ovalifolium desmodium and Endeavour stylo.

The experimental design was a split-split plot with shade as the main plot treatment, defoliation as the sub-plot and legumes as the sub-sub-plot treatment with three replications. As usual, the legume seeds were initially inoculated with appropriate rhizobia prior to sowing in 2 m x 2 m plots in full sunlight.

All legumes received a basal fertilization of 30 kg P/ha as triple superphosphate and 50 kg K/ha as muriate of potash and a similar rate of maintenance fertilizer per year split-applied after each harvest.

The inoculated seeds were broadcast in the plots at a seeding rate of 5 kg/ha for Endeavour stylo, hetero and ovalifolium desmodium and at 15 kg/ha for the centro, puero and caeruleum on June 1981. The legumes established well except hetero which was finally omitted due to poor establishment. The five legumes were allowed to grow in full sunlight for four months, and were subsequently cut to a stubble height of 15 cm prior to imposition of the four shade levels obtained by placing different densities of screen cloth over a wooden frame, 2 m above the ground over the plots. Each shaded block measured 12 m x 10 metres.

The legumes were harvested at 10- and 15-weekly intervals from October 1981 to September 1982. All species were cut to a 15-cm cutting height and the harvested materials weighed, subsampled and oven-dried at 80°C as before for DM yield estimation.

Statistical Analysis

Data were subjected to an analysis of variance for a split-plot design in the pot trial and a split-split plot design in the field trial. Where necessary, logarithmic transformation of the data was made before analysis to equalize variances. The means were ranked for shade tolerance.

RESULTS

Dry Matter Production

Pot trial

Shade reduced significantly (P<0.01) the cumulative DM yield of the 14 legumes as illustrated by the regression curves *(Figure 1)* and regression equations *(Table 3)*.

The overall mean cumulative DM yield at SG 0, SG 1, SG 2, SG 3 were 36.5, 25.7, 16.5 and 10.6 g/pot respectively *(Table 4)* giving an average reduction of 30%, 55% and 71% of DM yield for a corresponding reduction in 44%, 66% and 82% photosynthetic quantum flux.

A positive linear relationship between DM yield and light (PHAR) reduction in most of the legumes was obtained except for calopo, ovalifolium desmodium and caeruleum which had optimum yield projected at 57% of the PHAR in full daylight.

The legumes with the highest DM yield (significantly higher at P< 0.01 than the others) across all shade levels were calopo, puero and caeruleum *(Table 5)*. Ovalifolium desmodium, centro and Alyce clover ranked fourth, fifth and sixth respectively. However, the *Stylosanthes* spp. grew poorly under heavy shade (SG 3). Zornia, triflorum and Peruvian leucaena were the lowest yielders at all shade levels. The interactions of shade and legumes were also significant (P<0.01).

Since direct comparison of the legumes for shade tolerance was made difficult by the variability in intrinsic growth rate of the different species, the relative DM yield which was the per cent yield at a particular shade level to that of the control, was taken as a measure of degree of shade tolerance.

Caeruleum and puero which were the best yielding legumes under shade, had also the highest mean relative DM yield (>70%), followed by Alyce clover (69.5%), calopo (69.2%) and centro (61.4%). Surprisingly, ovalifolium desmodium, noted for its shade tolerance, had a lower relative DM yield (66.0%). The *Stylosanthes* spp., zornia, Peruvian leucaena, Joint vetch and triflorum had relative DM yields of less than 55 per cent.

Field trial

Initial field swards of the legumes were well-established except for hetero which failed to thrive despite repeated planting

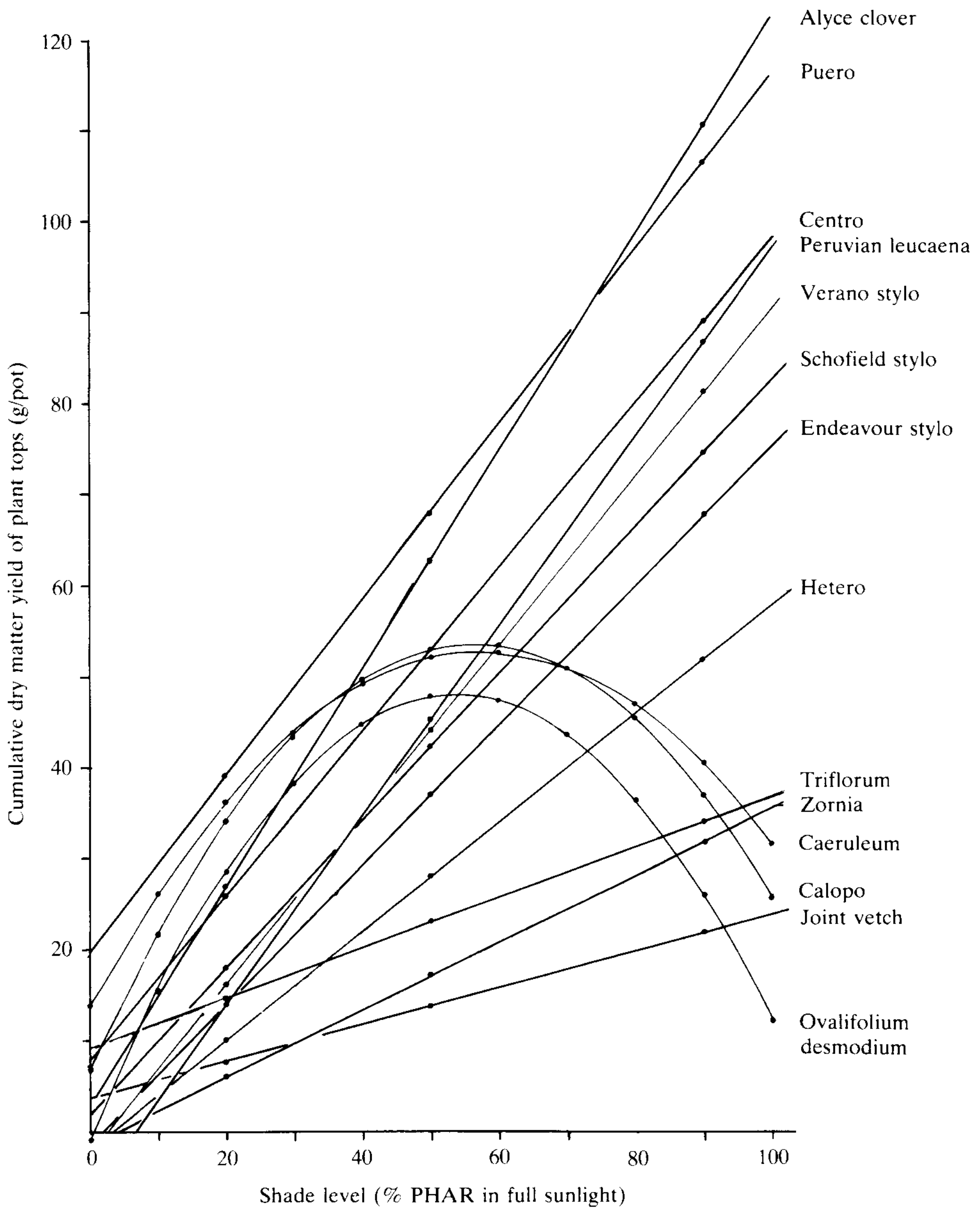

Figure 1. Dry matter yield responses by 14 tropical legumes in soil pot culture to shading.

and so was finally omitted from the treatment. Insect pests, feeding on the foliage of the legumes, especially *Epilachna indica,* posed the greatest problem in maintaining the pure swards of puero and centro. Fortnightly spraying with malathion at the recommended commercial rate was undertaken to prevent loss of stand. In addition, during the wet seasons, the legumes under heavy shade suffered from *Rhizoctonia solani* infestation, and damage to the stands was severe for the trailing legumes. These problems coupled with the light constraint and the small plot size resulted in the poor DM productivity of the trailing legumes particularly in caeruleum and puero *(Table 6).*

The effects of defoliation at ten and 15 weeks on the total DM production at the different shade levels are shown in *Table 6.*

Table 3. Regression equations for dry matter yield (g/pot) of forage legumes as affected by shade

Legume	Regression equation	Correlation of determination (r^2)
Joint vetch	$Y = 3.68 + 20.3S$	0.95**
Alyce clover	$Y = 3.03 + 119.6S$	0.63*
Caeruleum	$Y = 13.75 + 135.6S - 177.6S^2$	0.95**
Calopo	$Y = 6.57 + 166.9S - 147.8S^2$	0.90**
Centro	$Y = 7.72 + 90.5S$	0.89**
Hetero	$Y = -1.86 + 59.7S$	0.77**
Ovalifolium desmodium	$Y = -0.96 + 181.9S - 168.8S^2$	0.91**
Triflorum	$Y = 9.15 - 27.7S$	0.73**
Peruvian leucaena	$Y = -6.70 + 103.8S$	0.78**
Puero	$Y = 19.73 + 96.6S$	0.74**
Endeavour stylo	$Y = -1.27 + 76.6S$	0.97**
Schofield stylo	$Y = 1.94 + 80.6S$	0.97**
Verano stylo	$Y = -2.53 + 93.3S$	0.95**
Zornia	$Y = -1.30 + 36.8S$	0.95**

Y = DM yield

S = Shade as proportion of PHAR outside greenhouse

** = Significant (P = 0.01)

* = Significant (P = 0.05)

The total DM yield of the legumes over a one-year period was significantly different ($P<0.01$) amongst the species. Endeavour stylo, emerged as the highest DM yielder ($P<0.05$) across all the shade levels with 15-weekly cuts significantly higher than the 10-weekly cuts in total DM production. Defoliation frequency had no significant effects on yield in the other legumes. The overall mean DM yield of Endeavour stylo was 8 558 kg/ha/year, ovalifolium desmodium, caeruleum and puero yielded 4 119, 2 908 and 2 863 kg DM/ha/year respectively, while centro was the lowest yielder (2 096 kg/ha/year).

A sharp decline in the DM production at all shade levels with each subsequent harvest was observed *(Figure 2)*. This reflected the declining persistence of the legumes under shade, particularly at SF 3. Nevertheless, ovalifolium desmodium and caeruleum gave higher relative DM yields *(Table 6)*. Ovalifolium desmodium had 140% relative DM yield at SF 1, 118%–125% at SF 2 and 96%–107% at SF 3. Mean relative DM yields of the two cutting intervals for caeruleum were 165%, 150% and 96% under SF 1, SF 2 and SF 3 respectively. Although the best yielder, Endeavour stylo had a sharp decline in mean relative DM yield under shade indicating its shade intolerance (from 66% to 35% at SF 3). Results of the pot trial and the field experiment showed close similarity in DM yield response to shading in the five selected legumes. This was reflected in the high positive correlation coefficients *(Table 7)*.

Effects of Shade on Growth Components

Plant part composition

The DM yield decline with shading was also reflected in the reduction of leaf, stem and root dry weights of the legumes *(Figure 3)*. Across all the shade levels, puero continued to rank highest in leaf, stem and root dry weights followed by calopo, caeruleum and ovalifolium desmodium. The other legumes, namely

Table 4. Effects of shade levels on the overall mean plant performance of the 14 legume species in a pot trial

Treatment effect	Dry matter (g/pot)				Plant composition (%)			Nodule (No./pot)	Ratio		Leaf area (dm^2/pot)	SLA (cm^2/g)	%	
	Total yield	Leaf	Stem	Root	Leaf	Stem	Root		Shoot/root	Leaf/stem			DM	N
100% (SG 0)	36.5a	20.2a	16.3a	6.4a	47.1	38.0	14.9	153.0	6.49	1.24	29.55ab	227.2	25.9a	3.46b
56% (SG 1)	25.7b	14.0b	11.4b	3.5b	46.4	42.0	11.7	132.0	8.64	1.23	31.01a	300.9	23.5b	3.52b
34% (SG 2)	16.5c	8.8c	7.4c	1.5c	48.6	43.0	8.4	53.3	14.93	1.19	27.13b	378.1	20.4c	3.81a
18% (SG 3)	10.6d	5.8d	4.8d	0.9d	50.4	41.7	7.8	36.4	14.29	1.21	23.31c	397.1	18.9d	3.78a
Species effects	***	***	***	***							***		***	***
Shade x species	***	***	***	***							***		***	***

***($P<0.001$)
Means followed by the same letter are not significantly different ($P<0.01$)
SLA = Specific leaf area
DM = Dry matter
Total yield = (Stubble + leaf + stem)

Table 5. Effect of legume species on the overall mean plant performance at all shade levels in a pot trial

Legume	DM yield (g/pot)	Mean relative DM yield (%)		Dry weight (g/pot)			Ratio		Nodule		SLA		%	
		Tops	Root	Leaf	Stem	Root	Leaf/stem	Shoot/root	No./pot	Mean relative no. (%)	cm^2/g	Mean relative (%)	N	DM
Caeruleum	38.4a	73.2	51.6	23.1a	15.3a	5.1b	1.51	9.40	71.1	82	406.9	152	3.6cd	22.7d
Puero	39.6a	72.9	54.3	23.0a	16.7a	7.3a	1.38	7.32	193.9	89	467.3	139	3.6cd	20.0gh
Alyce clover	23.3c	69.5	56.8	12.0c	11.7c	3.8c	1.03	6.98	60.2	65	276.1	171	4.1b	22.5de
Ovalifolium desmodium	30.6b	66.0	49.7	18.5b	13.1b	3.9c	1.43	10.90	204.7	72	436.9	142	3.2e	22.1def
Peruvian leucaena	12.6c	52.3	40.9	7.0e	5.5e	5.2b	1.33	3.42	9.8	94	173.4	144	4.6a	24.8c
Calopo	36.4a	69.2	49.2	20.1a	16.3a	3.0d	1.23	13.89	39.7	92	494.1	139	3.8bc	20.9fg
Centro	28.3b	61.4	54.1	16.3b	12.0b	4.2c	1.36	7.72	60.5	42	387.6	126	3.1e	26.6b
Joint vetch	12.9c	48.8	45.5	5.8f	7.4c	1.7fg	0.75	8.62	60.4	42	246.1	153	3.3cd	30.9a
Zornia	6.1g	54.0	43.5	3.5g	2.7g	1.2gh	1.45	7.52	29.9	44	240.9	175	3.8bc	18.1i
Schofield stylo	22.9c	51.8	39.1	10.8c	12.2c	2.0ef	0.81	20.08	80.1	59	284.1	129	3.5cd	18.8hi
Verano stylo	18.9d	50.4	40.9	9.3d	9.5d	1.8fg	0.92	13.98	279.3	59	221.7	139	4.1b	21.5f
Triflorum	10.9ef	48.8	39.3	6.3ef	3.9ef	1.2gh	1.16	12.66	65.3	44	304.1	140	2.7f	23.2d
Hetero	8.8fg	55.0	49.8	4.9g	3.9ef	0.8h	1.29	13.62	65.3	57	305.5	142	3.6cd	21.2f
Endeavour stylo	19.2d	47.6	35.1	10.4d	8.8d	2.5de	1.03	19.08	80.5	46	352.3	152	3.7cd	17.5i

Means followed by the same letter are not significantly different ($P<0.05$).
SLA = Specific leaf area.

Table 6. Annual DM yield of 5 tropical legumes grown under 4 shade levels and defoliated at 2 intervals in a field trial

Legume	DM yield (kg/ha/yr) under various PHAR defoliated at									
	10-weekly interval					15-weekly interval				
	SF 0	SF 1	SF 2	SF 3	Mean	SF 0	SF 1	SF 2	SF 3	Mean
Ovalifolium desmodium	3 467(100)*	4 853(140)	4 328(125)	3 318(96)	3 992b	3 656(100)	5 117(140)	4 301(118)	3 904(107)	4 245b
Endeavour stylo	12 574(100)	8 256(66)	6 408(51)	3 839(31)	7 769a	14 651(100)	9 508(65)	7 591(52)	5 633(38)	9 346a
Centro	2 809(100)	1 854(66)	1 503(54)	1 147(41)	1 828d	4 055(100)	1 966(49)	1 834(45)	1 602(40)	2 364d
Caeruleum	1 944(100)	3 189(164)	2 888(149)	2 325(120)	2 587c	2 425(100)	4 011(165)	3 649(151)	2 827(71)	3 228c
Puero	3 889(100)	2 828(73)	2 414(62)	2 087(54)	2 805c	3 660(100)	3 040(83)	2 676(73)	2 309(63)	2 921d
Mean	4 937(100)	4 196	3 508	2 543	3 796	5 689	4 728	4 010	3 255	4 421

LSD (P=0.05) between means for defoliation frequencies = 709

Means followed by the same letter are not different (P<0.05) within a defoliation frequency.

( )* = Relative DM yield at various shade levels.

Table 7. Correlation coefficients between DM yield responses and shade levels in both pot and field trials in 5 tropical legumes

Legume	Correlation coefficients
Ovalifolium desmodium	0.91**
Caeruleum	0.94**
Centro	0.96**
Puero	0.99**
Endeavour stylo	0.99**

**Significant (P<0.01).

triflorum, zornia and hetero gave the lowest leaf, stem and root dry weights.

Expressed as a dry weight percentage of the whole plant (biomass), the overall mean root percentage of the 14 legumes decreased from 14.9% at SF 0 to 7.9% at SG 3 while the stem increased from 38.6% to 44.5% and the leaf from 47% to 49.7% respectively *(Figure 4* and *Table 4)*.

In caeruleum, calopo, zornia, Peruvian leucaena and puero, the leaf and stem percentages increased gradually with increasing shade levels. The *Stylosanthes* spp. had a more rapid rise in the stem percentages while their leaf percentages declined.

Leaf/stem ratio

The overall mean leaf/stem ratio across the 14 legumes was highest at SG 1 and declined with increasing shade intensity except at SG 3 *(Table 4)*.

There were two distinct responses to shade among the 14 legumes. The high-yielding legumes, *viz.* calopo, caeruleum, centro and puero, tended to maintain the leaf/stem ratio as a constant under moderate shade with a tendency to increase under heavy shade (SG 3). By contrast, the *Stylosanthes* spp. had declining leaf/stem ratios with increasing shade.

Shoot/root ratio

The shoot/root ratio of the 14 legumes also increased with dense shade *(Table 4)*. Highest increase in shoot/root ratio with shading was in Endeavour stylo and Schofield

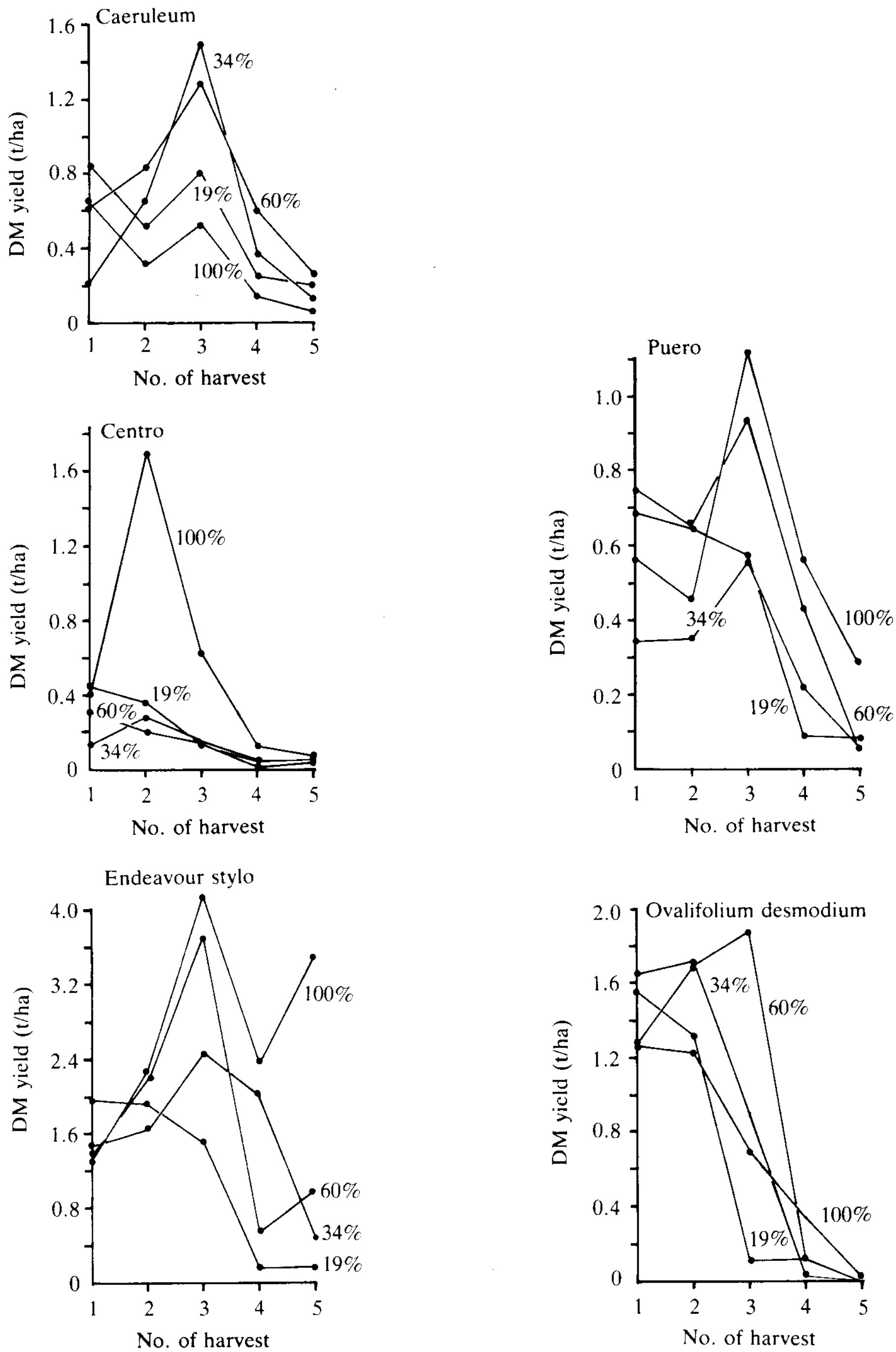

Figure 2. Dry matter yield of 5 tropical legumes grown in field under 4 shade levels harvested at 10-weekly intervals.

stylo at SG 2. Peruvian leucaena gave the lowest shoot/root value at all shade levels. In general, the highest yielding legumes, *viz.* caeruleum, centro and calopo, had relatively lower shoot/root ratio than the *Stylosanthes* species.

Leaf area

The overall mean total leaf area (dm^2/pot) of the 14 legumes increased non-

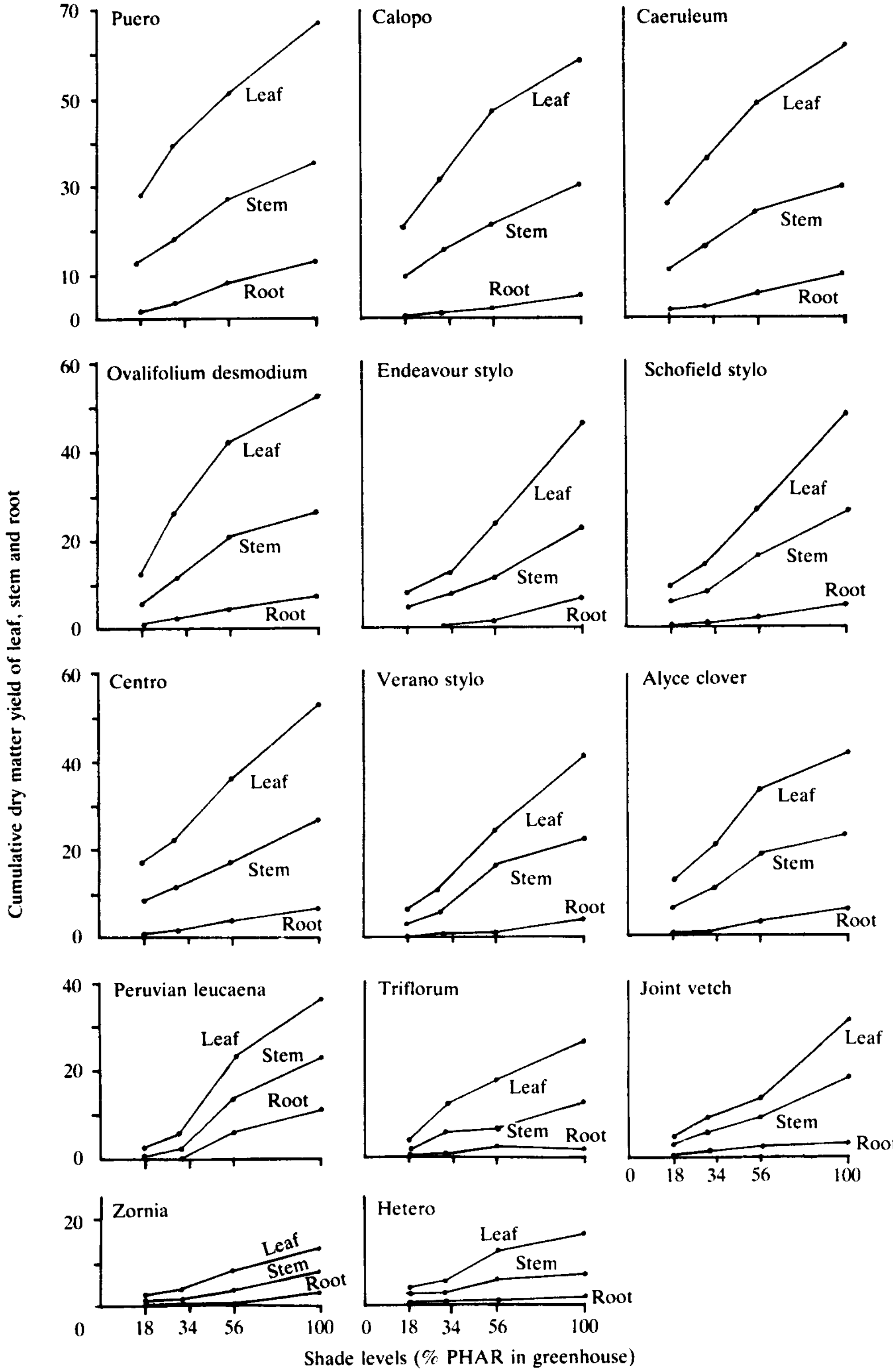

Figure 3. Cumulative dry matter yield of leaf, stem and root of 14 tropical legumes grown under 4 shade levels.

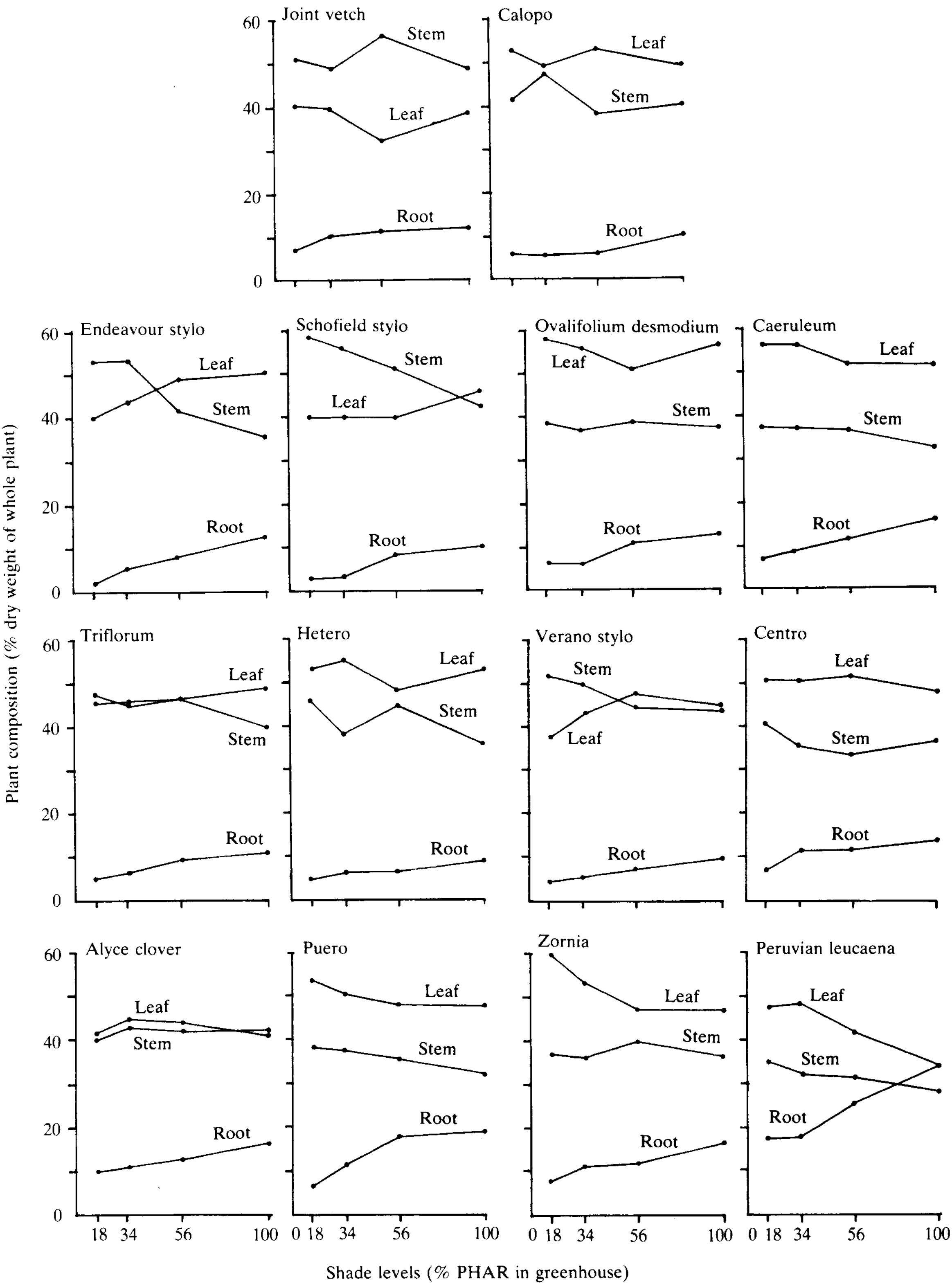

Figure 4. The influence of shade on the leaf, stem and root composition in 14 tropical legumes.

significantly from SG 0 to SG 1 but declined significantly ($P<0.05$) with increased shading except for the *Stylosanthes* spp. which had a marked decline in leaf area with increasing shade throughout. There were also significant differences between species ($P<0.05$) in leaf area, and shade x species interactions under shade *(Figure 5)*.

Calopo, puero and caeruleum ranked the highest in total leaf area per pot at all shade levels. This was followed by ovalifolium desmodium and centro. The *Stylosanthes* spp. ranked poorly under heavy shade. The other legumes, hetero, zornia and Peruvian leucaena ranked lowest.

Specific leaf area

The specific leaf area (cm^2/g leaf DM) of the legumes generally increased with increasing shade *(Table 4)*. Calopo had the highest specific leaf area followed by puero, ovalifolium desmodium, caeruleum, centro and Endeavour stylo. Zornia and the other *Stylosanthes* spp. lacked foliar plasticity to shading and hence were ranked amongst the lowest *(Table 5)*.

Dry Matter Percentage

The DM percentage of the plant tops in the 14 legumes decreased ($P<0.01$) with

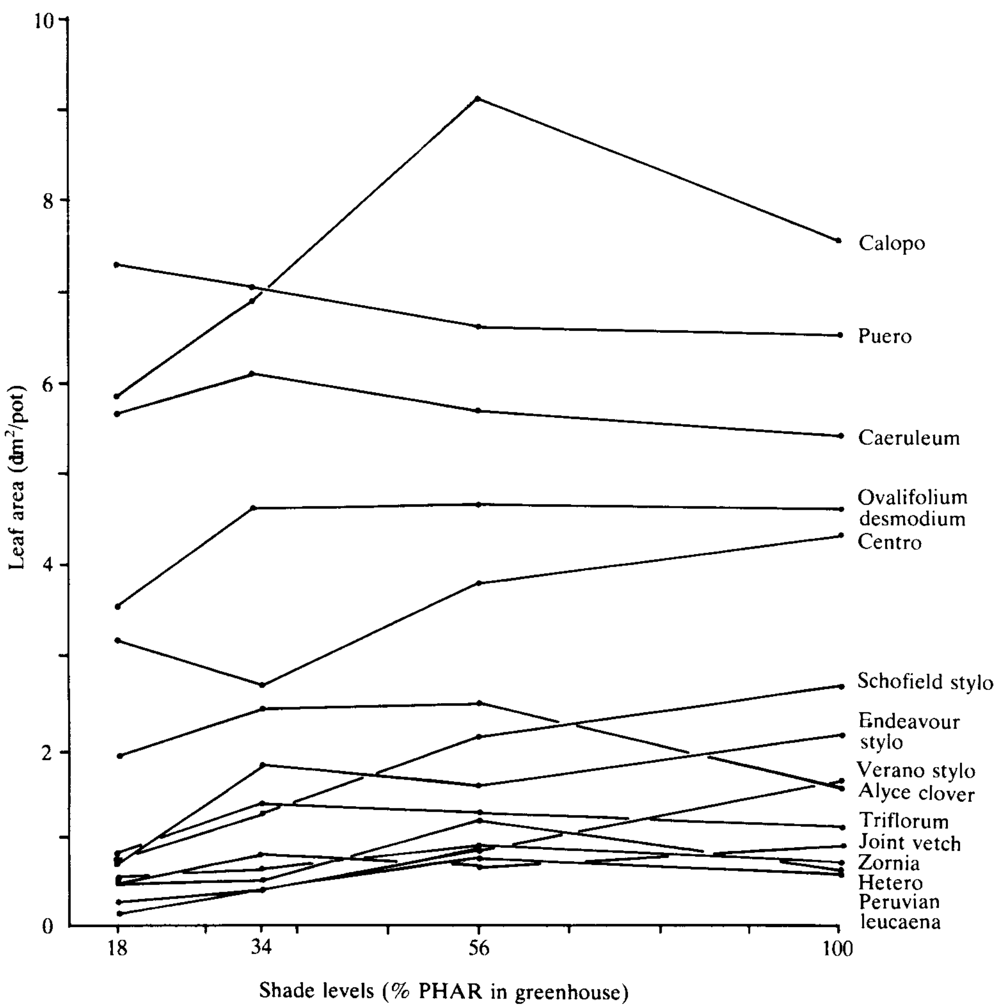

Figure 5. Leaf area of 14 tropical legumes as affected by 4 shade levels.

shade levels *(Figure 6)*. The woody legumes, namely Joint vetch, Peruvian leucaena and centro, had the highest DM percentage across all shade levels. The DM percentage of the *Stylosanthes* spp. especially Endeavour stylo declined from 22.2% at SG 0 to 14.3% at SG 3. Dry matter of zornia declined from 26.2% at SG 0 to 12.4%, the lowest at SG 3. The highest yielding legumes had higher DM which varied from 26.7% at SG 0 to 17.7% at SG 3.

Nodulation

Nodule count generally declined with increasing shade intensity in all the legumes studied *(Table 4)*. The average nodule count across all legume species declined from 153/pot at SG 0 to about 36.4/pot at SG 3. Unfortunately, nodule size was not measured, but visually the nodules appeared better developed at SG 1 than at SG 2 and SG 3. Ovalifolium desmodium and Verano stylo

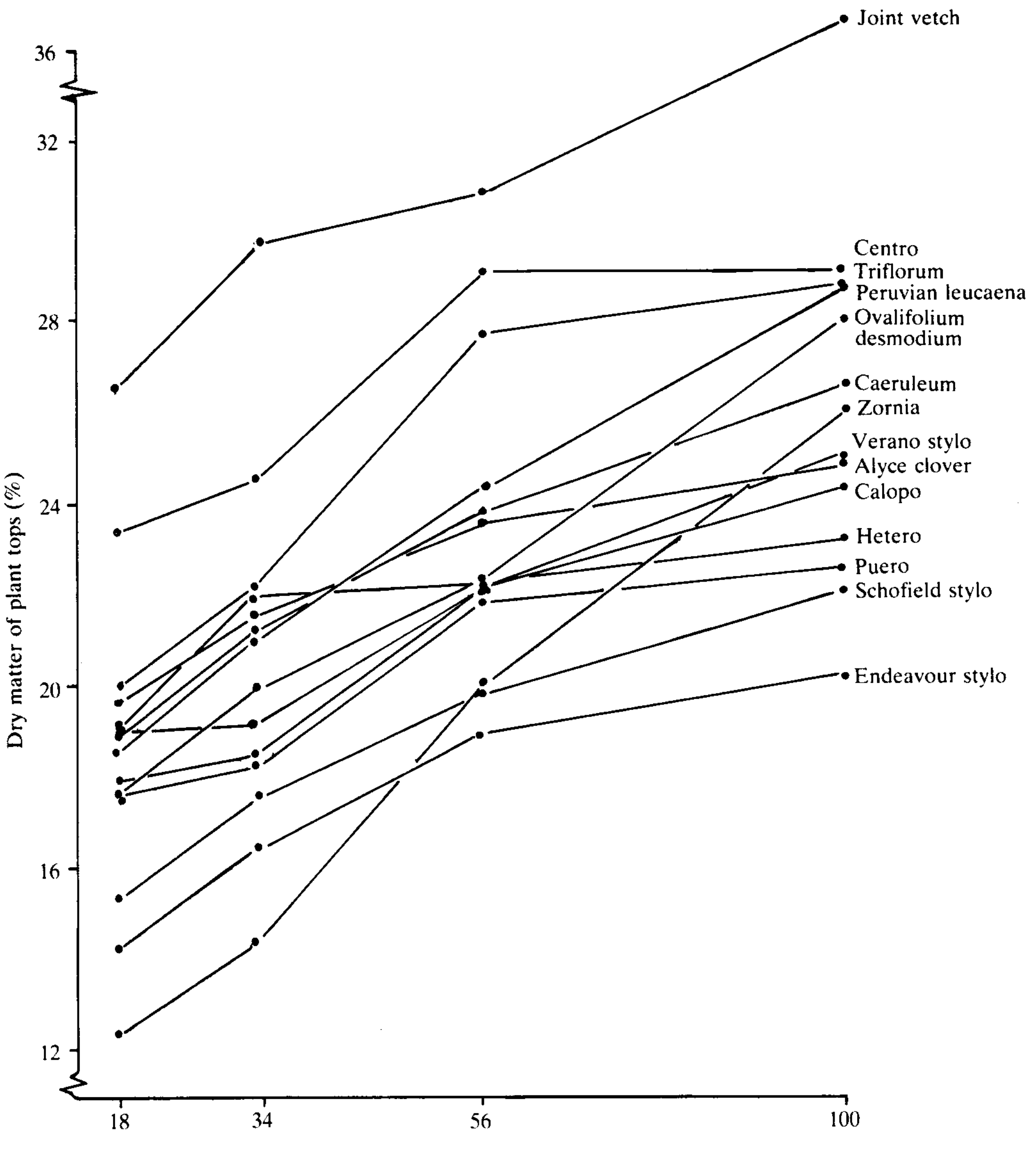

Figure 6. Dry matter of plant tops in 14 tropical legumes grown under 4 shade levels in the greenhouse.

gave the highest nodule count per pot at SG 1 but their nodules were generally small and scattered over the entire root system. Puero and Verano stylo gave the highest nodule count at SG 3.

Large nodules were noted in centro and puero which had a crown-type of nodulation. Caeruleum had fairly large nodules which were scattered over the entire root system. Alyce clover produced small nodules clustered around the crown root. The *Desmodium* spp. and zornia had numerous small nodules. Those of Peruvian leucaena were branched, large and concentrated at the crown, but the nodule count was low at all shade levels.

Nitrogen

Overall mean nitrogen concentrations of the legumes increased by 1.8%, 10.0% and 9.3% from SG 0 to SG 1, SG 2 and SG 3 respectively. Generally, there were no significant differences in nitrogen concentration between SG 2 and SG 3 but the nitrogen concentration at these two shade levels were significantly higher ($P<0.01$) than that at SG 0 *(Table 3)*.

Alyce clover, centro and hetero had reduced nitrogen content with shading while Schofield stylo, puero and ovalifolium desmodium showed little response. The lowest yielding legumes gave the highest nitrogen percentages, *viz.* Peruvian leucaena, Verano stylo and zornia *(Table 5)*. The highest yielding species such as calopo, caeruleum and puero were among the lowest in nitrogen percentage.

Vigour and Persistence

Regrowth vigour in the pot trial is defined as the percentage of the relative DM yield of the second harvest over that of the first harvest for each shade level. Due to variability in the regrowth vigour among the legumes, the relative regrowth vigour which was the relative percentage of the regrowth vigour at a shade level to that in 100% PHAR of the greenhouse for each legume, was adopted for comparison, and the data are shown in *Table 8*.

Shading generally decreased the relative regrowth vigour in all the legumes with the greatest decline at SG 3.

Of particular interest was the sharp decline in relative regrowth vigour of the hetero, Joint vetch and *Stylosanthes* spp. with increasing shade intensity. By contrast, the relative regrowth vigour decline in higher yielding legumes like ovalifolium desmodium, caeruleum, puero and calopo was less marked, particularly at moderate shade levels (SG 1 and SG 2). Centro, however, showed a marked decline from SG 2 onwards. The low yielding legumes, especially triflorum, were high in regrowth vigour rating at all shade levels.

In the field trial, persistence of the five legumes were expressed as the percentage of the relative DM yield at the last harvest over that of the first harvest for the 10-

Table 8. The effects of 3 shade levels on the relative regrowth vigour of 14 tropical legumes as compared to that grown in 100% PHAR (SG 0) in the greenhouse

Legume	Relative regrowth vigour* (%) at 4 shade levels				
	SG 0	SG 1	SG 2	SG 3	Mean
Joint vetch	100	38.8	47.6	6.7	48.3
Alyce clover	100	57.8	33.0	4.2	48.8
Caeruleum	100	81.1	57.8	12.9	63.0
Calopo	100	59.8	70.7	18.8	62.3
Centro	100	92.7	12.6	4.2	52.4
Hetero	100	38.7	38.5	18.7	49.0
Ovalifolium desmodium	100	95.5	67.0	7.8	67.6
Triflorum	100	146.1	54.3	18.9	79.8
Peruvian leucaena	100	65.2	53.1	32.2	62.6
Puero	100	95.0	64.4	12.9	68.1
Schofield stylo	100	48.4	41.0	6.9	49.1
Endeavour stylo	100	35.9	24.4	7.8	42.0
Verano stylo	100	66.9	35.1	8.5	52.6
Zornia	100	88.4	97.8	6.2	73.1

$$\text{*Regrowth vigour} = \frac{\text{DM yield at 2nd harvest}}{\text{DM yield at 1st harvest}} \times 100$$

weekly cutting frequency for each shade level. Except for Endeavour stylo, the other legumes had very low persistence rating at all shade levels *(Table 9)*. Persistence rating declined with shade intensity. Centro, ovalifolium desmodium and caeruleum were the only legumes which had slightly higher persistence rating at SF 1 than at SF 0.

Table 9. The effects of 4 shade levels on the persistence of 5 tropical legumes defoliated at 10-weekly intervals

Legume	Persistence[+] (%) at 4 shade levels			
	SF 0	SF 1	SF 2	SF 3
Ovalifolium desmodium	1.8	7.5	1.2	0.4
Endeavour stylo	57.7	45.1	30.7	8.9
Centro	4.5	22.8	20.5	15.4
Caeruleum	20.6	31.0	19.4	19.4
Puero	62.4	18.2	16.7	13.0

[+]Persistence = $\frac{\text{DM yield at 5th harvest}}{\text{DM yield at 1st harvest}} \times 100$

Obviously, ovalifolium desmodium showed the worst persistence rating at all shade levels. Puero was high at SF 0 in persistence rating but declined rapidly under increasing shade, while Endeavour stylo generally had better persistence rating at all shade levels except at heavy shade (SG 3).

Overall Shade Tolerance

The ranking on the mean total DM yield, regrowth vigour, root dry weight, total leaf area, shoot/root ratio, DM percentage, relative specific leaf area, relative leaf area and relative nodule number across all shade levels are summarized in *Table 10*.

Generally, all these attributes declined with shade intensity except shoot/root ratio and mean specific leaf area. The only difference among the legumes was the intensity of the changes of these attributes as affected by shade.

The legumes with the lowest mean rank could be considered to possess some degree of shade tolerance. These shade-tolerant legumes tended to have higher nodule number, root dry weight, leaf/stem ratio, specific leaf area and DM yield but lower shoot/root ratio. Caeruleum which was ranked first had projected a yield optimum at 57% daylight, was high in leaf/stem ratio and in relative DM yield.

Puero was ranked second in the overall shade tolerance rating. It was the highest yielding legume across all shade levels despite reduced yield under shading. Ovalifolium desmodium ranked third for overall shade tolerance rating while Peruvian leucaena was fourth, despite its poor yielding capacity. Its overall mean relative DM yield was 52.3% *(Table 5)*. However, it had the highest nitrogen percentage in the plant tops. Alyce clover came out fifth.

Calopo had been rated high in DM yield, leaf area, relative nodule count and relative cumulative DM production but its low relative specific leaf area, shoot/root ratio, DM percentage and leaf/stem ratio resulted in it being ranked number six. The main disadvantage of this legume was its poor regrowth vigour under shade. Centro was moderate in shade tolerance but ranked among the top legumes in DM percentage.

Stylosanthes spp. showed yield reduction as light was decreased and were much inferior to the commonly used plantation legumes. Verano, Schofield and Endeavour stylo were among the lowest in the overall ranking.

The other legumes, triflorum, hetero, zornia and Joint vetch were never outstanding in shade tolerance. All of them had low prostrate growth habit and were low in DM yield production even in full sunlight although triflorum and zornia showed high regrowth vigour in all shade levels.

Except for ovalifolium desmodium, the higher yielding legumes, puero, caeruleum and calopo, were of the creeping or trailing type. These legumes that had creeping ability appeared to compete better

Table 10. Tropical legumes ranked for mean performance on 10 agronomic attributes under shading

Legume	DM yield	Relative cumulative DM yield	Regrowth vigour	Root dry wt.	Shoot/ root ratio	Leaf/ stem ratio	Leaf area	Relative SLA	Dry matter	Relative nodule count	Mean
Caeruleum	2	1	5	3	7	4	3	5	5	4	3.9
Puero	1	2	3	1	3	7	3	12	11	3	4.5
Ovalifolium desmodium	4	5	4	5	8	3	4	8	7	5	5.3
Peruvian leucaena	11	9	6	2	1	1	14	6	3	1	5.4
Alyce clover	6	3	12	6	2	5	6	2	6	7	5.5
Calopo	3	4	7	7	11	9	1	11	10	2	6.5
Centro	5	6	9	4	5	6	5	14	2	12	6.8
Zornia	14	8	2	13	4	2	13	1	13	14	8.4
Triflorum	12	12	1	12	9	11	10	9	4	11	9.1
Joint vetch	10	13	13	11	6	14	11	3	1	13	9.5
Verano stylo	9	11	8	10	12	12	9	10	8	8	9.7
Hetero	13	7	11	14	10	8	12	7	9	9	10.0
Endeavour stylo	8	14	14	8	13	10	7	4	14	10	10.2
Schofield stylo	7	10	10	9	14	13	8	13	12	6	10.2

Ranking: 1 = best and 14 = worst.

SLA = Specific Leaf Area.

for light and hence could grow faster compared with the prostrate herbaceous ones.

DISCUSSION

Shade-tolerant plants are known for their efficient use of low light of irradiance for nett photosynthesis, carbon dioxide uptake and growth (BJORKMAN and HOLMGREN, 1966; BOARDMAN, 1977). They have evolved morphological and physiological mechanisms to regulate their development in such a way that optimum utilization of irradiance fluctuations within the plantation canopies could be achieved (LUDLOW, WILSON and HESLEHURST, 1974; WONG and WILSON, 1980). Identification of shade-tolerant forages for production in monospecific plantations could help to alleviate the problem of light competition.

The aim of the pot trial was to identify shade tolerance potential among the 14 legumes while the field trial served to ascertain the productivity of dry matter and persistence of the selected species under reduced light and frequent defoliation. Although artificial shading did not reflect the actual irradiance fluctuations under the canopy of plantation crops, the different shade levels used could help to identify the spectrum of shade tolerance in legumes from the large number of legumes available for initial assessment. The results of the pot trial revealed significant and variable responses of the species to shade levels. Of the 14 legumes assessed, the majority (11 legumes) behave like sunplants with linear relationships in DM production to light levels. Only three species, caeruleum, calopo and ovalifolium desmodium, gave significant quadratic responses to shade intensity with optimum yield projected around 57% full sunlight but their DM yields even at the optimum light level were generally lower than those of puero, Alyce clover and centro. In the overall shade tolerance assessment involving ten attributes, caeruleum ranked first, ovalifolium desmodium third and calopo sixth. Puero which was the highest yielding legume across all shade levels, ranked second while the *Stylosanthes* spp. were among the lowest.

The shade-tolerance of the legumes was manifested in the degree of adaptive changes in specific leaf area, leaf/stem ratio, shoot/root ratio, dry matter percentage and leaf area in response to light attenuation in order to optimize light utilization. The shade-intolerant legumes (*Stylosanthes* spp.) had reduced leaf/stem ratio and excessive increase in shoot/root ratio resulting from the increased DM stem at the expense of both the root and the leaf *(Figures 3* and *4)*. In the shade-tolerant species, such as caeruleum, ovalifolium desmodium and puero, the leaf and stem fractions increased proportionately to root reduction, thereby maintaining a balance between leaf and stem percentages under shade. This is best illustrated by Alyce clover which had minor changes in leaf and stem percentages under dense shade *(Figure 4)*. It thus appears that unequal changes in the plant parts as a result of shading could be detrimental to the overall growth performance of the species as was found in the *Stylosanthes* spp. (SILLAR, 1967; ERIKSEN and WHITNEY, 1982; CHEN and OTHMAN, 1984).

Poor regrowth of the tropical legumes under shade could be anticipated because of the reduced root system affecting mineral and water uptake as well as the decline in nett assimilate rates, resulting from a decrease in photosynthetic rate (LUDLOW *et al.,* 1974). Also, the process of biological nitrogen fixation could be affected by the reduced nodule production and the deleterious effects of defoliation on nodulation (BUTLER, GREENWOOD and SOPER, 1959; WHITEMAN and LULHAM, 1970).

In spite of the reduced nodule count under shade, the nitrogen percentage in plant tops of the legumes was significantly increased ($P<0.01$) with shade intensity as depicted by Joint vetch, calopo, triflorum, zornia and Peruvian leucaena. This could be attributed to the reduced growth of the shaded legumes. However, only three legumes, Alyce clover, centro and hetero had reduced nitrogen concentration with increasing shade reflecting the consequences of the decline in nodule numbers. Endeavour stylo, Schofield stylo, puero and ovalifolium desmodium showed little response to shade in nitrogen content, which is consistent with the findings of BATHURST and MITCHELL (1958), WONG and WILSON (1980), and ERIKSEN and WHITNEY (1982).

In the field trial, Endeavour stylo which was considered shade intolerant in many respects in the pot trial, produced the highest DM production at all shade levels despite the sharp decline in productivity over time *(Figure 6)*. Ovalifolium desmodium, caeruleum and puero were ranked second, third and fourth respectively for dry matter yield. The better yield performance of Endeavour stylo could be attributed to its fast establishment and regrowth after cutting and its erect growth habit compared with the slow regrowth and the trailing habit of puero and caeruleum even in full sunlight.

Since Endeavour stylo was initially established in full sunlight, the earlier cumulative root reserve could provide temporarily the energy for the subsequent good regrowth under shade. Towards the end of the trial, the DM yield of the last two harvests of Endeavour stylo under heavy shade had declined to relatively low levels *(Figure 2)*. Persistence at SF 3 was low. Already its shade intolerance was indicated by the large decline in relative DM yield from 100% at SF 0 to 35% at SF 3. Although the shade-tolerant legumes were lower in DM yield, these legumes (caeruleum and ovalifolium desmodium) showed better growth under reduced light *(Table 5)*. WHITEMAN, BOHORQUEZ and RANACOU (1978) also reported species in the genus *Desmodium* to be shade-tolerant.

Unfortunately, ovalifolium desmodium did not persist well under frequent cutting. Hence, low yields were obtained in the subsequent harvests. Similar findings in ovalifolium desmodium were also reported by CHEN and OTHMAN (1984), and prolonged cutting was recommended. Caeruleum and puero did not persist well even in full sunlight. Their poor persistence could thus account for the different ranking of shade tolerance in the legumes between pot and field trials. Also the low DM production of these two legumes could be due to the small plot size which led to the underestimation of their productivity by virtue of the trailing stolons thriving beyond the plot. The poor growth of centro under shade was due mainly to the severe forage damage by leaf-sucking insects, *e.g. Epilachna indica* and this masked the shade tolerance potential.

Under normal circumstances, many tropical legumes in full sunlight could not persist long even under optimum management (WHITEMAN, 1969; WONG, 1982). With the additional light constraint, the problem of legume vigour and persistence under plantations could be aggravated. This is well illustrated in the field experiment where the five forage legumes could not persist under shade to give continual high DM production *(Table 8)*. This lack of persistence, especially amongst the trailing legumes, could be attributed to increased removal of a large number of growing apices from the elevated stature of the shaded legumes (JONES, 1974). Hence, proper cultural management is necessary to ensure their survival and DM productivity. Although the DM yield potential of shade-tolerant legumes under reduced light was higher compared with their productivity in full sunlight (control), their yielding capacity was in no way comparable to that of the fast-growing legumes like Endeavour stylo. At SF 0, the mean DM yields of ovalifolium desmodium, centro, caeruleum and puero were 26%, 25%, 16% and 28% respectively that of Endeavour stylo. Even under dense shade (SF 3), their yields were 76%, 29%, 54% and 46% respectively that of Endeavour stylo. It thus appears that shade-tolerant species may not necessarily be high-yielding, but moderate production on a long-term basis with high persistence under shade situations could be the desirable qualities.

Agronomic Implications

The linearity of yield response to light levels in the forage legumes was obvious with the exception of ovalifolium desmodium and the *Calopogonium* spp. which had significant quadrative responses to shade intensity with optimum DM production around 57% light (PHAR). Generally, the top growth and the root dry weight of the legumes were reduced by shading. The root growth appeared to be more affected by shading than the plant tops. The development and utilization of forage crops under plantation crops would have to take into consideration these growth sensitivities of the tropical legumes to shade.

In view of their poor persistence and low productivity under increased shading, their utilization under plantation crops should be geared towards lenient cutting or grazing in order to favour their survival. Proper management of both the plantation and cover crops, as well as the grazing animals, is essential to ensure the success of such an integration. Grazing to a stubble height of 20–25 cm had been recommended to ensure the constant supply of feed resources (JAVIER, 1974). Hence, ovalifolium desmodium, centro, puero and *Calopogonium* spp. which have been identified as comparatively more shade tolerant for these purposes, may be used.

Nonetheless, the applicability of the research results in forage integration with plantation crops will depend not only on the agronomic desirability, but also the economic and practical feasibility. With the vast acreage under tree crop plantation cultivation and the abundance of unexploited forage legumes and grasses in the early years of plantation establishment, coupled with the limited cheap agricultural land for ruminant production in the country, the development of ruminant livestock integration with plantation crops has great potential particularly in the current context of the National Agricultural Policy of maximization of farm production per unit area.

ACKNOWLEDGEMENTS

The authors would like to express sincere appreciation to Mr. Ahmad Shokri Hj. Othman for statistical analyses and Dr. Heng Cheng Kok and his staff of the Central Analytical Services for plant chemical analyses in this study.

ABSTRACT

In a comparative evaluation of 14 tropical legumes under pot culture in a greenhouse, *Calopogonium caeruleum* was the best in overall shade tolerance followed by *Pueraria phaseoloides, Alysicarpus vaginalis* and *Desmodium ovalifolium*. The *Stylosanthes* species and *D. triflorum* and *D. heterophyllum* were ranked the lowest. The best dry matter (DM) yielders across all shade levels were *P. phaseoloides, C. mucunoides* and *C. caeruleum*. A reduction in the photosynthetic quantum flux (PHAR) by 44%, 66% and 82% of that in the unshaded control resulted in a corresponding overall mean DM yield reduction of plant tops by 30%, 55% and 71% of that of the unshaded control. *Calopogonium mucunoides, C. caeruleum* and *D. ovalifolium* gave quadratic response in DM yield to light levels with an optimum at 57% of PHAR in full sunlight.

In the field trial, *Stylosanthes guianensis* cv. Endeavour gave the highest annual DM yield at all shade levels followed by *D. ovalifolium, C. caeruleum* and *P. phaseoloides*. *Centrosema pubescens* had the lowest DM production. A reduction in PHAR by 40%, 66% and 82% of that in full sunlight resulted in a corresponding decline in overall mean DM yield by 36%, 43% and 60% of that in the unshaded control.

Generally, the five forage legumes were not persistent in maintaining high DM productivity over harvests. Dry matter percentage of plant tops, specific leaf area and shoot/root ratio increased with

shading intensity while root percentage and nodule number declined. Leaf and stem percentages increased marginally with shade intensity. Leaf area increased non-significantly under low shade but declined in heavy shade.

Nitrogen content differed among species and generally increased among shade regimes except for the most intense shade.

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Accepted for publication on 18th May, 1985.